Research Record

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A Fresh Look at Michigan's Bridge Decks

MDOT Investigates New Design and Inspection Procedures

Editor's note: In this issue of the Research Record*, I have done something a little different. Rather than basing this issue on one particular study, I have pulled together information from three different studies — all of them related to bridge decks. This includes a study of Type K concrete to help control cracking of bridge decks; a comparison of shallow and deep bridge deck overlays; and the development of procedures for efficient evaluation of bridge decks.*

-Scott Bershing
Research Record *Editor*

Engineers in the Michigan Department of Transportation (MDOT) are constantly investigating new materials and technologies in an effort to provide motorists with the highest quality, safest roadways in the most cost-efficient manner possible. This is no easy task, as one usually doesn't lead to the other. This was the impetus of three studies recently completed by the Construction and Technology (C&T) Division of MDOT — to help provide the materials, methods, and means necessary in order to increase longevity and decrease costs.

Type K Concrete

by John Staton, Construction & Technology Division

Emphasis these days is focused on constructing bridges using High Performance Concrete (HPC). Early HPC was defined as concrete possessing special performance characteristics that cannot be achieved using conventional materials or methods. An example of early attempts to engineer HPC focused on selecting materials which would produce concrete with exceptionally low permeability characteristics in efforts to reduce corrosion of the reinforcing steel. However, along with increased density of the concrete came the inherent increases in concrete strengths. This may be fine for concrete subjected to pure axial compressive stresses. However, it may not be true for concrete experiencing bending or tensile stresses, which may increase the concrete's cracking susceptibility. Important questions often overlooked when engineering a concrete mix design include, "What is the potential for cracking, and how might these cracks effect the long-term performance of the overall structure?"

From a structure designer's perspective, it is understandable to specify a particular type of concrete based on its empirical design strength. Assuming maintenance and rehabilitation schedules are representative, and true-to-life, for all bridges, one could anticipate achieving these targeted results. However, all bridge decks are not constructed on a desktop, nor in a controlled laboratory environment. The real-life environmental and materials-related variables have great impacts on concrete's crack susceptibility, particularly at early ages.

The Federal Highway Administration (FHWA), therefore, refined its definition of HPC, addressing eight long-term performance parameters; four related to strength, and four related to durability. In general, these relationships are designed to assist engineers in selecting performance grades of concrete as a function of the conditions that the concrete will experience.

It is interesting to note when inspecting bridge deck cracking that many of the transverse cracks occur at fairly consistent and nearly uniform spacing along the bridge deck. Some of these cracks travel only partial-depth into the slab, while others (seen leaking from the bottom-side of the deck) propagate full-depth. However, one certainty is that the majority of bridge deck cracks continue to a depth at least to the top mat of reinforcing steel.

Since a fair assumption could be made that bridge decks do crack, the issue is to determine what are the crack-initiating mechanisms, and what can we do to reduce (if not eliminate) the likelihood of their development. The steel deck reinforcement, and "beam-to-slab" composite reinforcement can be seen as internal restraint within the concrete. As the concrete undergoes plastic and drying shrinkages, internal restraints from these immovable objects induce tensile stresses within the slab. When these internal restraint stresses exceed the tensile capacity of the concrete (which is evident at early ages), something has to give. The result usually shows up as a transverse crack — a release of energy.

MDOT's Materials Research Group began a long-term investigation to study whether improvements could be made to their concrete bridge deck mix designs. The intent of the study was to potentially reduce restraint tensile stresses, thus reducing the number of transverse bridge deck cracks. The focus of this particular study was to evaluate the long-term field performance of "Type K" (shrinkage reducing) Portland cement for concrete bridge deck applications.

The concept behind Type K concrete is to establish an early-age internal mechanism within the concrete to offset early-age restraint stresses that may develop. Restraint tensile stresses develop when the concrete, which is bonding to the deck reinforcing steel and shear developers, begins to shrink. From the concrete's internal perspective, it sees itself being pulled in two opposite directions. Type K Portland cement is unique in the sense that it induces an early-age controlled expansion reaction within the concrete. Granted, the overall relative shrinkages for Type K concrete are similar to those of a comparable conventional concrete. However, the initial expansion during the Type K's early age, semi-plastic phase, "grips" and imposes tensile stresses into the reinforcing steel; causing a slight "prestressing" action of the reinforcement within the concrete mass. As the concrete begins to cure, it undergoes conventional plastic and drying shrinkages, and therefore, the steel is permitted to relax. This relaxation of the reinforcing steel follows in-line with the concrete shrinkage, ultimately equalizing and establishing a theoretically zero-stress environment between the reinforcement and concrete.

To date, MDOT has constructed six concrete bridge decks using Type K concrete with excellent results. Granted, a few transverse cracks have been noticed, but, for the most part, they can be attributed to high-stress concentrations located near beam and abutment or diaphragm intersections in heavily skewed bridges.

The consensus was that Type K concrete for bridge deck applications decreases the likelihood of transverse deck cracking. However, it was also noted that without the sufficient internal restraint provided by the reinforcement, the Type K concrete undergoes its chemical expansion, then simply shrinks and cracks similar to (if not worse than) conventional Portland cement concrete.

Since this field study has produced a sufficient level of confidence that Type K concretes do indeed aid in reducing deck cracking, future actions are to expand its use throughout the state for upcoming projects. Additional studies related to reducing bridge deck cracking are also planned to study the field performance of new-to-the-market liquid chemical-based shrinkage-reducing concrete admixtures.

Shallow vs. Deep Bridge Deck Overlays

In addition to exploring the use of different materials to improve the performance and longevity of bridge decks, the use of alternate methods of resurfacing is also being explored. In a study that was initiated in 1991, MDOT began looking into the use of deep bridge deck overlays as an alternative to shallow overlays. Due to the fact that construction costs for deep overlays are similar to those for shallow overlays, an improvement in performance and longevity would justify the more frequent use of deep overlays.

A shallow overlay is typically 38 mm thick, and consists of latex-modified concrete that is placed after hydro-demolishing the original surface to a depth of 19 mm. The deep overlay consists of removing the deck concrete below the top reinforcement, replacing any deficient rebar, and placing Grade 45 D Modified concrete such that a depth of 75 mm covers the top transverse reinforcement.

In order to compare the effectiveness of the deep overlay versus the shallow overlay, three structures were selected in relatively close proximity to each other, with each having nearly identical traffic loads and environmental conditions. All three of the structures are four-lane spans supported by steel beams and carry traffic over I-75 in Saginaw County. They include the Busch Road, Townline Road, and Curtis Road structures.

The Curtis Road bridge is a cantilevered structure with a cantilever length of 2.3 m. It has a total length of 78 m, a skew angle of 36°, and six support beams spaced at 1.8 m. The Curtis Road structure was fitted with a shallow overlay.

Both the Busch Road and Townline Road structures are of simple support design, and both received deep overlays. The Busch Road structure has a total length of 91m, a skew angle of 45°, and six support beams spaced at 1.9 m. The Townline Road bridge has a total length of 81m, a skew angle of 38°, and six beams spaced at 1.9 m.

The same contractor performed the rehabilitation on all three of the structures, which helped to reduce the number of variables in the study. It also validated the performance comparison between the two resurfacing methods and helped to ensure that all of the decks were rehabilitated in a similar manner. The work on the decks was completed in October of 1991. The decks were evaluated in June 1998 after weathering seven winters.

Evaluation Procedures

The deck of each structure was chain-dragged to determine areas of delamination. The delaminated areas were highlighted with orange paint. Visible cracks in the bridge decks were then marked with yellow paint. Finally, the decks were wetted and allowed to dry. This revealed minor cracking, which was marked with pink paint. The bridge decks were then photographed from a height of approximately six meters from a lift bucket to give a panoramic view of the deck. Three core samples were taken from each deck for later testing of shear strength to determine the bond characteristics of the overlay.

Results

The majority of cracks in the deep overlays are located in the joint areas, with a few diagonal cracks present. These diagonal cracks are the result of the skew angle of the bridge deck, not the deep overlay. The deck with the shallow overlay showed severe random cracking at the joints and light random cracking throughout the deck.

The results of the shear testing showed good bonding strength on both the deep and shallow overlays. The shear tests were performed using MDOT's inhouse direct shear test method.

Conclusions

Based on the performance of the deep overlays in this study, it appears that the use of deep overlays is a viable alternative to shallow overlays; however, there are a couple of caveats.

Although the cost for deep overlays was comparable to shallow overlays for this study, this may be due to the fact that all of the decks were covered under one contract. As such, the bid prices for the completion of the deep overlays in this study may not be an accurate representation of the true costs.

As a general rule, it appears as if the additional cost of the latex-modified concrete in the shallow overlay helps to equalize the cost when compared to the additional labor, equipment and material needed for the deep overlays.

A second concern with deep overlays is the potential of punching through the deck when removing the material. This would increase the total cost of the project considerably, as additional forming would be required under the deck. Due to this, MDOT has limited the use of deep overlays to decks with underside deficiencies (visible spalling, delamination, wet areas, patches, etc.) of less than 5 percent. In addition, due to the anticipated 25 to 30 year life expectancy of the deep overlay, compared to 10 to 15 years for a shallow overlay, deep overlay activities will be initiated earlier in the life of the existing bridge deck.

Even with these concerns, it appears as if the use of deep bridge deck overlays is a promising way to extend the life of bridge decks while stretching repair and maintenance dollars even farther.

Development of Procedures for Efficient Evaluation of Bridge Decks

In a joint study with the University of Michigan (U of M), MDOT examined the physical parameters surrounding the performance of bridge decks, and how they affect one another. This included studying the varying effects of material properties, mechanisms of failure, environmental conditions, and traffic loads. During the study, U of M reviewed MDOT's inspection records, bridge inventory deck data, and detailed deck delamination surveys.

They inspected several bridge decks and did selective material tests. They studied how traffic loads affect bridge decks, and used finite element modeling to show how stress is distributed through deck slabs as a result of dead loads, live loads, and temperature effects.

As a result of this research, two reports will be published this coming Spring. The first is a Research Report entitled *Development of a Procedure for Efficient Evaluation of Bridge Decks.* This report will provide background information about traffic loads affecting bridge decks, material properties, mechanisms of failure, failure scenarios, and analytical tools available for deck analysis. The second report will be a *Deck Evaluation Guide*, which will provide practical information to engineers who are making decisions about when to repair, rehabilitate, or replace bridge decks. The *Guide* will identify typical modes of deterioration found on Michigan bridge decks, discuss bridge deck deterioration rates, and discuss available deck evaluation procedures. The *Guide* will provide reference to, and serve as a supplement to, the appropriate condition rating and decision making tools used by MDOT, such as the National Bridge Inventory (NBI) ratings, PONTIS, and the MDOT Bridge Deck Repair Matrix (shown in Table 1).

CONDITION STATE			ANTICIPATED RESULT TO NBI		
Deck Surface Deficiencies (1) NBI # 58a	Deck Underside Deficiencies (2) NBI # 58	Suggested Actions (3)	Item # 58a Deck Surface	Item # 58 Underside of Deck	Next Anticipated Evaluation
N/A	N/A	CSM Acitivies	No Change (5)	No Change (5)	1 to 8 years
2% to 5% (4) NBI = 5 & 6	< 5%, NBI > 5	Deck patch / Seal Cracks / Polymer Overlay	Up by 1 pt.	No Change (5)	1 to 8 years
	>5% NBI < 5	Deck Patch	Up by 1 pt.	No Change	1 to 8 years
		Hold	No Change	No Change	3 to 10 years
5% to 15% NBI = 5	N/A	Hold	No Change	No Change	3 to 7 years
15% to 30% NBI = 4 & 5	< 5%, NBI > 5	Deep Concrete Overlay	Up by 3 pt.	No Change	25 to 30 years
	5% to 30% NBI = 3, 4 or, 5	Shallow Concrete Overlay	Up by 2 pt.	No Change	10 to 15 years
	>30% NBI = 2 or 3	Bituminous Cap	Up by 2 pt.	No Change	3 to 5 years
> 30% NBI = 3 & 4	< 5%, NBI > 5	Deep Concrete Overlay	No Change	No Change	20 to 25 years
	5% to 30% NBI = 3, 4 or, 5	Shallow Concrete Overlay	Up by 2 pt.	No Change	10 years
		Bituminous Cap	Up by 2 pt.	No Change	3 to 4 years
	>30% NBI = 2 or 3	Replace Deck	NBI now 9	NBI now 9	40 + years
		Bituminous Cap	No Change	No Change	1 to 3 years

1. Percent of deck surface area that is spalled, delaminated, or patched
2. Percent of the deck underside area that is spalled, delaminated, wet, or map cracked
3. The “Do Nothing” option or “Hold” option implies that there is ongoing maintenance filling potholes with cold patch and scaling of incipient spalls
4. Epoxy overlays should only be used when the deck has very little deterioration
5. Sustains the current condition state longer

Table 1: MDOT Bridge Deck Repair Matrix

Contact Information

For more information regarding Type K concrete, contact John Staton at (517) 322-5701, or send email to STATONJ@state.mi.us. For more information regarding the study of shallow and deep bridge deck overlays, contact Bryon Beck at (517) 322-5722, or via email at BECKB@mdot.state.mi.us. For more information regarding the development of the efficient bridge deck evaluation precedures, contact Dave Juntunen at (517) 322-5707, or via email at JUNTUNEND@mdot.state.mi.us.

Reference Material

Comparison of Standard and Deep Bridge Deck Overlay Performances
Report Number: R-1368
Bryon Beck
Michigan Department of Transportation
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